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DYNAMIC SKILL-BASED CALL ROUTING

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Field of the Invention

The field of the invention relates to telephony systems and more particularly to automatic call distributors used with private networks.

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Background of the Invention

Automatic call distribution systems are known. Such systems are typically used in an organizational context as a means of distributing telephone calls among a group of agents of the organization. Agents are typically segregated into groups to serve particular call targets within an organization.

Often the organization disseminates a single telephone number to its customers and to the public in general as a means of contacting the organization. As calls are directed to the organization from the public switch telephone network (PSTN), the automatic call distribution system directs the calls to its agents based upon some algorithm, typically based upon availability. For example, where all agents are considered equal, the automatic call distributor (ACD) may distribute the calls based upon which agent position (telephone) has been idle the longest.

In other systems, where skill is considered essential for call handling, a call may be directed to an agent (or agent group) considered the most skilled for the call considered. In these systems, a database of customer records is maintained. Customers are identified to the ACD and database by features such as automatic number identifier (ANI).

5 In order to staff an ACD, an organization often
relies on historical levels (in Erlangs) of incoming
calls to the individual call targets. A manager of
the ACD may examine the historical call loading
10 records, add or subtract a percentage of the
historical loading based upon a most recent call
history (e.g., the most recent week or month), and
estimate a staffing level based upon those
calculations. Alternatively, some organizations have
15 relied upon commercially available predictive
software (i.e., force management packages) which
calculates daily staffing levels based upon historic
information.

20 Once daily staffing levels have been estimated,
agents are scheduled based upon those estimates.
Where more than one organizational call target is
involved (e.g., sales agents, service agents,
outgoing call campaign agents, etc.), requiring
different agent skills, each group is separately
25 staffed based upon an Erlang estimate for that group.

As an alternative to staffing individual groups,
some systems group all agents together and assign a
skill rating to each agent. Calls are then assigned
based upon the skill rating of the agent for handling
25 that type of call.

For example, where a single group is used, an
ACD will always look for and assign the call to the
most qualified agent. However, some agents are more
qualified than others. Because of the differences in
30 qualifications, some agents receive more calls than
others, resulting in an inequitable work load.

Further, where all agents are grouped together,
an Erlang rate for any one group becomes irrelevant.
For example, one benefit of using a common group
35 relates to economies of scale. Two separate groups

that separately require 10 agents each would typically only require 18 agents from a common pool of agents.

Further, it is difficult, if not impossible for
5 call center management to know how many agents are serving a particular call target. Because of the difficulty of determining agent loading, it is also difficult to project staffing requirements in a
10 shared agent environment.

Where all agents are grouped together, staffing estimates must be based upon an Erlang rate of the organization as a whole. Basing a staffing estimate upon an organization as a whole is subject to large errors. Because of the importance of call handling
15 through ACDs, a need exists for a method of assigning agents which is more flexible than the individual group method, but which may still be staffed based upon Erlang estimates of the individual call groups.

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Summary

A method and apparatus are provided for assigning agents of an automatic call distributor to incoming calls of a plurality of call types handled by the automatic call distributor. The method
25 includes the steps of determining a target occupancy matrix including a target occupancy for each agent of the agents of the automatic call distributor for each call type of the plurality of call types. The method further includes the steps of processing a call of a
30 first type of the types determined in the target occupancy matrix and assigning the call to an agent of the agents of the automatic call distributor with a largest relative difference between an actual occupancy of calls of the first type handled by the
35 agent and the target occupancy of calls of the first

type determined for the agent in the target occupancy matrix.

Brief Description of the Drawings

5 FIG. 1 is a block diagram of an ACD system in accordance with an illustrated embodiment of the invention; and

 FIG. 2 is a flow chart of process steps that may be used by the system of FIG. 1.

10 Appendix I is an unpublished paper entitled "AUTOMATIC GENERATION OF AGENT OCCUPANCY MATRIX: REQUIREMENTS AND ALGORITHM DESCRIPTION" that describes (in pseudo-code and otherwise) an algorithm that may be used by the system of FIG. 1.

15 Detailed Description of a Preferred Embodiment

9 FIG. 1 is a block diagram of an ACD system 10, generally, using skill based call routing under an illustrated embodiment of the invention. Under the
20 embodiment, the ACD 18 may receive calls over a number of trunk lines 28 through the PSTN 16 from customers 12, 14 of the ACD 18. Along with the
 calls ^{a call processor (CP) of} the ACD 18 may receive information about the calls from the PSTN 18. For example, the ACD 18 may
25 receive an identifier of a caller from an automatic number identification (ANI) service operating from within the PSTN 16. The ACD 18 may also receive information about a dialed number through a dialed
 number identification (DNIS) service or direct inward
30 dial (DID) information from the PSTN 16.

 The ACD 18 may also be programmed to place calls at the same time as it receives calls. For example, the ACD 18 may conduct an outgoing call campaign to existing or potential customers at the same time as

it receives calls from existing or potential customers.

In the case of outgoing calls, a list of telephone numbers (i.e., call targets) may be entered through the PC 11 and sequentially transferred to the ACD 18. Upon receipt of a call target, the ACD 18 may seize a trunk line of the trunks 28 and transfer the target telephone number to the PSTN 16. When the target answers, the ACD 18 connects the target to an agent.

In the case of an outgoing call, the PC 11 may transfer an identifier of the call target to the ACD 18. Alternatively, the ACD 18 (e.g., by reference to a database) may determine an identity of the call target based upon the dialed number.

From the information received from the PSTN 16 (or PC 11), the ACD 18 may classify the call as a particular work type based upon the identity of the call target and whether it is an inbound or outbound call. For example, the ACD 10 may be owned and operated by a department store. Individual call targets may include women's clothing, men's clothing, footwear, housewares, appliances, electronics, furniture, hardware, automotive and garden. Other internal call targets may include catalog sales or technical support for one or more of the other call targets.

As opposed to creating semi-permanent groups of agents and queuing calls to the appropriate group, the ACD 18 places agents in a single pool and directs all calls to this pool. Agents are rated according to skill level in each call type. A target agent responsibility (occupancy) matrix is created to allocate portions of agents' time to each call type, based on the agent skill in handling that call type,

as well as call type workload and other enterprise-related factors. Table I is a simplified example of a target occupancy matrix.

TABLE I

	Tocc(j)	WORK TYPE #1	WORK TYPE #2	WORK TYPE #3
AGENT #1	85%	10%	60%	15%
AGENT #2	50%	20%	20%	10%
AGENT #3	90%	30%	30%	30%
AGENT #4	90%	70%	10%	10%

5
FIG. 2 is a flow chart that may be followed in creating the target occupancy matrix. Reference will be made to FIG. 2 as appropriate to an understanding of the invention.

10 In the over-staffed situation (agents available when a call arrives), the call is handled by the agent whose actual occupancy is furthest from the target occupancy for that call type. Actual occupancy may be defined as the amount of time an
15 agent has spent on a particular work type divided by a time of a reporting period (e.g., a workshift) and expressed as a percentage. Table II is an example of an actual occupancy matrix.

TABLE II

	Tocc(j)	WORK TYPE #1	WORK TYPE #2	WORK TYPE #3
AGENT #1	85%	10%	50%	15%
AGENT #2	50%	19%	20%	10%
AGENT #3	90%	27%	30%	25%
AGENT #4	90%	50%	10%	10%

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Where a call comes in (e.g., for work type #1) a comparison is made of the deviation of each agent from the target occupancy for that work type. As may be seen by comparing Tables I and II, agent #4 has a target occupancy for work type #1 of 70% and an actual occupancy for work type #1 of 50%. Since agent #4 has the greatest deviation, the next call of work type #1 would go to agent #4.

In the understaffed situation (no agents available and calls are queued), a call will be selected from the queue of a work type which will bring an available agent's actual occupancy level closest to the target for that agent. If there is more than one call of that work type, then the call with the highest priority or the longest time in queue may be chosen.

The system may be used to provide real-time reporting in the form of a display of actual versus target agent occupancy for each call type, and provides a mechanism for adjusting the targets. This solution has the advantage that it gives call center management, working through the PC 11 (hereinafter referred to as the "user"), a mechanism for easy control over agent assignments in the form of target occupancies, and it provides uniform agent utilization where desired.

Under the illustrated embodiment, each agent is evaluated and assigned a skill level for his proficiency in any number of skills related to servicing calls directed to each particular type of call target. An agent may be assigned a skill level expressed as any number between 1.0 and 2.0 (i.e., where 2.0 indicates the highest level of proficiency), in increments of 0.1. Table III is an

example of a skills matrix that may be used to classify agents.

TABLE III

	ENGLISH	SPANISH	WOMENS CLOTHING	MENS CLOTHING	FOOTWEAR
AGENT #1	1.1	0.0	1.5	1.9	1.3
AGENT #2	1.9	1.3	1.5	1.1.	1.8
AGENT #3	1.5	1.5	1.7	1.2	0.0

5

Agent proficiency may be regarded as one example of semi-permanent data that may be used by the PC 11 in creating a target occupancy matrix. Permanent and variable data may also be used.

Ins (4) Permanent data may include a list of skill types required for each work type. A list may also be provided of the work types handled by the system 10. A minimum skill level may be included for each skill required for each work type. A priority number may be provided for each work type.

Variable data may include a target total agent occupancy (Tocc(i)) for each agent i. For example, an agent may have a target total agent occupancy of 20 85, 95 or even 100%. Further, the variable data may include one or more target agent occupancies for the particular work types.

Variable data may also include an expected call load for each work type. The expected load may be in 25 Erlangs. The variable data may also include a list of agents scheduled to work during any time period.

Ins (5) Once the permanent, semi-permanent and variable data have been provided to the PC 11, the PC 11 may form an initial target occupancy matrix. In forming 30 an initial target matrix, the PC 11 must determine

(5) whether an agent is qualified to be given an occupancy value for any particular work type within the target matrix.

Ins(6) To determine the suitability of an agent for a work type, the PC 11 evaluates each agent's qualifications with regard to the work type. Each agent i must possess a skill level which exceeds a minimum level required by the work type. In effect, the skill $ASkl(i,k)$ of agent i for skill k must exceed the skill requirement $WSkl(j,k)$ for work type j in skill k . Further, any particular work type may require a skill set including more than one evaluated skill. Stated differently, for an agent to be assigned to a work type, $ASkl(i,k) \geq WSk1(j,k)$ for all k .

In the example of Table II, a call from/to a particular geographic area may be known to include a large Spanish population. Calls regarding a telephone number associated with this area regarding footwear would require at least two skills (i.e., the ability to speak Spanish as well as a knowledge of footwear). A minimum skills level may be required in each skill.

To evaluate an agent for a work type where multiple skills are required, the PC 11 solves for the euclidean distance $ACap(i,j)$ between the agent i 's skills and work type j 's requirements. Expressed differently, the PC 11 solves the equation as follows:

$$ACap(i,j) = \sqrt{\sum_k (ASkl(i,j) - WSk1(j,k))^2, (WSkl(j,k) > 0)}.$$

If for any k, such that $ASkl(i,k) < WSk1(j,k)$ (i.e., agent i does not satisfy the minimum skill requirements of work type j), then

$$5 \quad ACap(i,j) = -\sqrt{\sum (ASkl(i,k) - WSk1(j,k))^2}, (WSkl(j,k) > ASkl(i,k)).$$

Expressed differently, where $ACap(i,j) \geq 0$, the agent may be regarded as qualified for the work type.

Where $ACap(i,j) < 0$, the agent may not be regarded as
10 qualified for the work type.

Ins (7) Once the capability of each agent is determined, the PC 11 may form 100 an initial target matrix. To populate the matrix, the PC 11 may first retrieve a set of occupancy values entered by the user. For
15 example, the user may enter a total occupancy $Tocc(i)$ for a particular agent i over all work types. The user may also enter an occupancy value (" $X(i,j)$ ") for the agent i regarding one or more work types j. Ultimately, the user could specify the entire scope
20 of the initial target matrix, but this is not necessary since the PC 11 will supply occupancy values where necessary.

Further. as will be discussed below, the user may designate some agents as primary agents for a
25 work type. Other agents may be designated, or may become, secondary agents.

Where an agent is to be designated as a primary agent of a work type, that agent would be expected to have a higher occupancy rating for the work type,
30 than secondary agents. The user may explicitly specify the occupancy rating for a work type or allow the PC 11 to specify the occupancy rating by merely designating primary agents for some work types. While any value may be used, an occupancy rating

X(i,j) of 70% may be used by the PC 11 as a default value when that agent is designated as a primary agent by the user.

5 Upon retrieving the occupancy values entered by the user, the PC 11 first verifies that the sum of the occupancy ratings X(i,j) assigned to an agent among the work types is less than, or equal to, the Tocc(i) for that agent. The PC 11 may then take steps to fully populate the initial target matrix.

10 The PC 11 may first determine 102 the number of effective agents available by summing the Tocc(i) values for the agents schedules to work for any particular time period. For example, if two agents were available and each had a Tocc(i)=50%, then the
15 number of effective agents in this case would be one. The number of effective agents for the system 10 may be determined by solving the equation as follows:

$$effectiveAgents = \sum_{i=1}^{numOfAgents} Tocc(i) .$$

20 A residual staffing level ("residualStaffing") may be determined by subtracting the sum of the predicted workload of each work type ("Prdtworkload(j)") from the number of effective agents as follows:

25

$$residualStaffing = effectiveAgents - \sum_{j=1}^{numOfWorkTypes} Prdtworkload(j) .$$

If there are more effective agents than the sum of predicted workloads, then extra agents are distributed
30 among the work types based upon loads and staffing priorities. If there are fewer effective agents than the sum of predicted workloads, then each work type is assigned fewer agents than is suggested by its workload.

The number fewer is dependent upon the work loads and priorities ("relativePriority"). In either case, a target number of effective agents for each work type ("TargetFTE(j)") is determined as follows:

5

$$perPortion = \frac{residualStaffing}{\sum_{j=1}^{numOfWorkTypes} (relativePriority(j))(prdtworkload(j))}, \text{ and}$$

$$TargetFTE(j) = (perPortion) (relativePriority(j)) (prdtworkload(j)) + prdtworkload(j).$$

10

Ins (8) To populate the initial target matrix, the PC 11 sequentially selects agents and randomly selects work types. The occupancy X(i,j) given agent i to work type j may also be random or may be a percent of total time or a fixed value, so long as the sum of all occupancies for the agent is less than a user specified Tocc(i) or 100%.

Tocc(i) may be set by the user at anywhere from zero to 100%. If not specified by the user, the Tocc(i) for an agent will have a default value of 100%. If Tocc(i) is set by the user, the PC 11 will not change it. Similarly, if the user selects a work type occupancy X(i,j) for an agent, the PC 11 will not change it.

It should be kept in mind that while the PC 11 randomly selects work types, any selected work type will be skipped if an agent is not skilled for that work type (i.e., ACap(i,j)<0). The PC 11 may then randomly select another work type. The PC 11 may also check that the occupancy does not exceed a maximum ~~allows~~ number of work types allowed per agent ("MaxNumWtPerAgent"). If it does, the PC 11 goes on to the next agent.

For instance, where a $Tocc(i)$ for an agent is manually selected by the user at 80% and there are four work types, then the PC 11 may ultimately assign an occupancy of 20% to each work type. If based upon the agent capability $Acap(i,j)$, the agent is not qualified for the first work type, then the PC 11 may assign work type occupancy values of 30% to the second and third work type and 20% to the last work type.

10 In general, the PC 11 will repetitively assign work types $X(i,j)$ until each agents' $Tocc(i)$ is reached. Preferably, the PC 11 uses small values (i.e., fractional occupancies) of $X(i,j)$ to maximize the number of work types ($numOfAssignedWts(i)$).

15 To ensure that each agent gains experience in other work types, a minimum number of work types ($MinNumWTPerAgent$) may also be specified. Where the threshold value for a minimum number of work per agent ($MinNumWTPerAgent$) is not met, the PC 11 may divide up one or more of the agent's occupancies among other work types to achieve the threshold value.

25 Once an initial target matrix is achieved, the PC 11 may compute a number of assigned equivalent full time agents for each work type ($assignedFTE(j_0)$). The PC 11 also calculates an average agent capability ($aveCap(j_0)$) by averaging the $ACap(i,j_0)$ of the agents given an occupancy for work type j_0 .

30 Once the initial target occupancy matrix is achieved, the PC 11 may begin to ^{iteratively}~~interactively~~ repair the matrix. Iterative repair may be performed continuously to accommodate changes in call loading or periodically based upon some objective loading

standard (e.g., queue length for call groups). Where iterative repair is performed periodically, the iterative process may begin and continue for a fixed number of iteration cycles specified by the user.

Ins (95) As a first step in the ^{iterative} ~~interactive~~ repair process, the PC 11 may compute an objective function value ("computeObjectiveFunctionValue()"). The objective function value provides a means of evaluating a new (iterative) target matrix over a previous target matrix. The value of the objective function may be determined as follows:

Value=(weightFTE) (scoreFTE)+(weightSkills) (scoreSkills),

15 where "weightFTE" is a number indicating how important it is to allocate the right amount of staffing to each work type to match a predicted workload (a default value of weightFTE may be set equal to 1), where "weightSkills" is a number
20 indicating how important it is to maximize the average of aveCap(j) per work type (weighted by the agents' occupancy for that work type) (a default value of weightSkills may be set equal to 10), where

25
$$scoreFTE = \sum_{j=1}^{numOfWorkTypes} (targetFTE(j) - assignedFTE(j))^2 \text{ and}$$

$$scoreSkills = \sum_{j=1}^{numOfWorkTypes} (aveCap(j) - bestCap(j))^2,$$

30 where "bestCap(j)" is the highest relative ACap(i,j) score for the work type j.

Once the objective function value is determined, agents are again selected sequentially one-by-one.

For each selected agent, a first work type is selected randomly from a list of work types in which the agent already has an occupancy. A second work type is then selected at random and a portion of the agent's occupancy is transferred 104 from the first work type to the second work type.

Ins (10) A revised target matrix is then created using the transferred occupancy. A new objective function value is determined 106 from the revised target matrix. If the new objective function is smaller 108 than the previous objective function, then the change 110 in occupancy is made to the target matrix. If not, then the next agent is selected and the process is repeated.

15 In addition, before the change in occupancy is executed, the PC 11 performs the checks discussed above. For example, is the agent qualified to perform the work of the second work type?

In an alternative embodiment, the iterative repair may include selection of an overstaffed work type for which the agent has a non-zero occupancy value and selection of a second work type for which the agent is qualified. If the objective function is smaller, the change is implemented. Otherwise, the next agent is selected and the process is repeated.

The number of agents required for each work type (i.e., $\text{targetFTE}(j)$) for each work type j may be estimated from historical workload and Erlang tables, or from force management packages. For example, a prior history of call loading for a particular work type may be retrieved from an archive. The loading may be increased by some factor based upon most recent history to achieve an initial estimation of the number of agents required for each call type.

Iterative repair may be made periodically or only when required by call loading for a group.

Specifically, an increase in a call arrival rate of a particular call type over the initial (or later) loading estimate may be used to trigger iterative repair.

The need for iterative repair may be determined by a number of methods. For example, the length of time a caller spends in a call queue is one measure of call loading. However, since callers would be expected to become discouraged and hang-up after a short time period, it is not the only measure available.

One other simple measure of call loading may be based upon the number of calls directed to the call type per time period. Using well known Erlang calculation techniques and an average time per call, this can be converted into a required number of full time agents.

A specific embodiment of a method and apparatus for an improved skill-based call routing system according to the present invention has been described for the purpose of illustrating the manner in which the invention is made and used. It should be understood that the implementation of other variations and modifications of the invention and its various aspects will be apparent to one skilled in the art, and that the invention is not limited by the specific embodiments described. Therefore, it is contemplated to cover the present invention any and all modifications, variations, or equivalents that fall within the true spirit and scope of the basic underlying principles disclosed and claimed herein.

**Automatic Generation of Agent Occupancy Matrix:
Requirements and Algorithm Descriptions,
by Mei Wang.**

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Section 1: Introduction

The target occupancy matrix is defined as:

$X(i,j)$ = target occupancy of agent i for work type j .

$\sum_j X(i,j) = Tocc(i)$, $Tocc(i)$ is the target total occupancy for agent i

Agent i is expected to spend $X(i,j)$ of all his/her time on work type j . The algorithm described in this document automatically assigns values to $X(i,j)$. This algorithm first initializes the agents' occupancies while guarantee that all hard constraints are satisfied. Then this algorithm iteratively repairs upon the current solution using an objective function that maximizes the match between the assigned staffing for each work type and the workload, as well as maximizes the skill levels of agents on their assigned work types. This algorithm is $O(nm)$, where n is the number of agents, m is the number of work types.

Section 2: Input

The input to the matrix generation algorithm includes are:

1. *NumOfAgents*, *numOfWorktypes*, *numOfSkills*
2. For each agent i :
 - $ASkl(i,k)$, ($1 \leq k \leq numOfSkills$, $1 \leq ASkl(i,k) \leq 10$), agent i 's skill level for skill k ;
 - $Tocc(i)$, this agent's target total occupancies ($0 \leq Tocc(i) \leq 1$),
 - $AllowedWTs(i)$: a list of work types agent i is allowed to work on. This must be a subset of all the work types agent i is capable of working on. Defaults to all work types agent i is capable of working on. (Note: in the current implantation, we have selected work types, meaning all the work types the agent must work on. In the C++ implementation, this will be changed).
 - (Optional), $UserPrimaryResWt(i)$, work type id where agent i is assigned primary responsibility by the user.
 - (Optional), $x(i,j)$, agent i 's occupancy for work type j ,
3. For each work type j :
 - $WSkl(j,k)$, ($1 \leq k \leq numOfSkills$, $1 \leq WSkI(i,k) \leq 10$), minimal required skill level for skill k ,
 - $StfPr(j)$, staffing priority for work type j
 - $PrdtWorkload(j)$, predicted workload for work type j
4. *UsePrimaryRes*: whether or not to assign primary responsibilities to agents
UsePrimaryRes = *True*: assign primary responsibilities,
UsePrimaryRes = *False*: do not assign primary responsibilities.
5. *PrimaryResValue*, ($0 \leq PrimaryResValue \leq 1$): the value of the occupancy for an agent with primary responsibility for a work type (note: right now, there is one number for

all agents; if needed, we can change this so that each agent may have different values). *PrimaryResValue* defaults to 70%.

6. Advanced inputs (inputs user should typically not change):
 - 6.1. *NumOfCycles*: number of times to run the algorithm to generate the matrix.
Default: *NumOfCycles* = 1.
 - 6.2. *MinNumWTPerAgent* and *MaxNumWTPerAgent*: minimal and maximal number of work types each agent can be assigned non-zero occupancy for.
 - 6.3. *WeightFTE*: a number indicating how important is to allocate the right amount of staffing to each work type to match the predicted workload. Default: *WeightFTE* = 1.
 - 6.4. *WeightSkills*: a number indicating how important it is to maximize the average of averageCapability per work type (the average capability of all agents working on each work type, weighted by agents' occupancies for that work type). Default: *WeightSkills* = 10.
 - 6.5. *MinOcc* and *MaxOcc*: minimal and maximal occupancy value. Defaults: *MinOcc* = 0.05, *MaxOcc* = 1.
 - 6.6. *MinOccToMove*: minimal occupancy value to move from one work type to another, used during matrix generation. Default: *MinOccToMove* = 0.05.

Section 3: Requirements

The algorithm must satisfy the following requirements:

1. Small changes in inputs should not result in dramatic changes in output. Small changes here means:
 - 1.1. Changes in one or a few agents' parameters:
 - User specified primary responsibility work type changes from one to another
 - Skill levels for a set of skills
 - Target total occupancy
 - Allowed work types
 - 1.2. Changes in one or a few work types' parameters:
 - Minimal required skill levels for a set of skills
 - Predicted workload
 - Staffing priority
2. The user may over specify constraints, in which case no solutions can be found. We should warn user of their conflicting inputs.
3. Must be fast enough for 500 agents x 50 work types.

Section 4: Algorithm for initial generation of occupancy matrix

The following notations are used in addition to the inputs stated above:

- $ACap(i,j)$: agent i 's capability for work type j .
- $BestCap(j)$: the largest capability for work type j of all agents
- $numOfAssignedWTs(i)$: the total number of work types agent i has non-zero occupancy.
- $AveCap(j)$: the average capability for work type j of all agents' capabilities for work type j , weighted by the agents' occupancies for work type j
- $TargetFTE(j)$: the target full time equivalent staffing for work type j .
- $AssignedFTE(j)$: the assigned full time equivalent staffing for work type j . It is the sum of all agents' occupancies for work type j .

Main():

1. Read in required user inputs (including agent skills, work type skills, user preferences, and partial occupancy matrix). Check input consistencies (for example, an agent must meet the minimum requirements for the work type that he is assigned primary responsibility for by the user).
2. Clamp the occupancy values set the user (clamped the values will not be changed by the algorithm).
For $i = 1$ to $numOfAgents$
 For $j = 1$ to $numOfWorkTypes$
 If $X(i,j)$ is set by the user then $X(i,j).userClamped = True$
 If $PrimaryResWt(i) = j$ then $X(i,j) = primaryResValue$, $X(i,j).userClamped = True$
3. ComputeTargetFTE()
4. ComputeAgentCapabilities()
5. $BestScore = 0$ (a global variable recording the best result so far);
 ReturnMatrix $\leftarrow ()$;
6. For $i = 1$ to $numOfCycles$:
 - 6.1. NewMatrix \leftarrow generateMatrix()
 - 6.2. If NewMatrix.score > bestScore then $BestScore = NewMatrix.score$;
 ReturnMatrix \leftarrow NewMatrix
7. Return ReturnMatrix

ComputeTargetFTE()

1. Compute relative priorities of work types. Staffing priorities are 1-10, with 1 being the highest. Each priority is associated with a relative Priority (ranges between 1 and 2, with increments of 0.1). Thus, work type priority 1, the highest, corresponds to relative Priority 2, work type priority 2 corresponds to relative Priority 1.9 and so on, work type priority 10 corresponds to relativePriority 1.1.
2. Compute number of effective agents:

$$effectiveAgents = \sum_{i=1}^{numOfAgents} Tocc(i)$$

3. Compute residual staffing:

$$residualStaffing = effectiveAgents - \sum_{j=1}^{numOfWorkTypes} Pr dtworkload(j)$$

4. If there are more effective agents than sum of predicted workloads, distribute residualStaffing to all work types based on their workloads and staffing priorities.
5. If there are fewer effective agents than sum of predicted workloads, each work type must be assigned fewer agents than required by its workload. The amount of agents fewer is dependent on the workloads and priorities.

$$perPortion = \frac{residualStaffing}{\sum_{j=1}^{numOfWorkTypes} relative Priority(j) * prdtworkload(j)}$$

$$targetFTE(j) = perPortion * relative Priority(j) * prdtworkload(j) + prdtworkload(j)$$

ComputeAgentCapabilities():

For $i = 1$ to $numOfAgents$,

For $j = 1$ to $numOfWorkTypes$

(a) If $\forall k, ASkl(i,k) \geq WSkI(j,k)$, where $1 \leq k \leq numOfSkills$, (i.e., agent i satisfies minimal skill requirements of work type j , thus capable for work type j), then:

$$ACap(i, j) = \sqrt{\sum_k (ASkl(i,k) - WSkI(j,k))^2}, (WSkI(j,k) > 0)$$

This is basically the euclidean distance between agent i 's skills and work type j 's required skill on skills required by the work type.

(b) If $\exists k$, s.t. $ASkl(i,k) < WSkI(j,k)$, where $1 \leq k \leq numOfSkills$, (i.e., agent i does not satisfies minimal skill requirements of work type j , thus not capable for work type j), then:

$$ACap(i, j) = - \sqrt{\sum_k (ASkl(i,k) - WSkI(j,k))^2}, (WSkI(j,k) > ASkl(i,k))$$

This is basically the negative of the Euclidean distance between agent i 's skills and work type j 's minimal skill requirements on skills where the agent does not meet the minimal requirements.

($ACap(i,j) \geq 0$ means the agent i has sufficient skills for work type j ; $ACap(i,j) < 0$ means the agent does not have sufficient skills for work type j).

GenerateMatrix()

1. Initialize occupancies: For $i = 1$ to $numOfAgents$
 - 1.1. If $usePrimaryRes = True$ then initialize primary occupancies:
If $UserPrimaryResWt(i) = j$ Then: $X(i, j) = primaryResValue$
Else: $X(i, j_0) = primaryResValue$ (random choose $j_0, j_0 \in allowedWTs(i)$)
 - 1.2. Initialize rest occupancies such that:
 - a) $\sum_j X(i, j) = Tocc(i)$
 - b) $MinNumWTPerAgent$ and $MaxNumWTPerAgent$ constraints are satisfied.
 - c) $X(i, j) > 0$ only if $ACap(i, j) \geq 0$.
 - d) Maximize $numOfAssignedWTs(i)$.
 - 1.3. Compute $assignedFTE(j)$, $aveCap(j)$, $\forall j, 1 \leq j \leq numOfWorkTypes$
2. Assign occupancies by iterative repair:
For $m = 1$ to $numOfIterations$:
 Score \leftarrow computeObjectiveFunctionValue()
 For $i = 1$ to $numOfAgents$:
 FromWT \leftarrow rndPickWT(i)
 (randomly select a work type to move occupancy from for agent i)
 ToWT \leftarrow rndPickWT(i) (randomly select a work type to move occupancy to for agent i)
 deltaOcc \leftarrow genDeltaOcc (generate a occupancy value to move from work type FromWT to work type ToWT)
 deltaScore \leftarrow computeDeltaScore
 (compute the delta of the objective function when moving occupancy)
 If allowableMove($i, FromWT, ToWT, deltaOcc$), then
 If $deltaScore < 0$, or with probability 0.01 (value of this probability is changable):
 then: move deltaOcc from work type FromWT to work type ToWT;
 Score \leftarrow Score + deltaScore
 Update $assignedFTE(FromWT)$, $assignedFTE(ToWT)$, $aveCap(FromWT)$, $aveCap(ToWT)$
3. Fine tune occupancies: (Note: although this does result in lower objective function, it does not make a difference in performance on the simulator)
 For $m = 1$ to $numOfFineTunIterations$:
 Score \leftarrow computeObjectiveFunctionValue()
 For $i = 1$ to $numOfAgents$:
 FromWT \leftarrow select an over-staffed work type where agent i has non-zero occupancy)
 ToWT \leftarrow select an under-staffed work type where agent i has capability
 deltaOcc \leftarrow minOccToMove
 deltaScore \leftarrow computeDeltaScore
 If allowableMove($i, FromWT, ToWT, deltaOcc$) and $deltaScore < 0$ then:
 move occupancy deltaOcc from work type FromWT to work type ToWT;
 Score \leftarrow Score + deltaScore
 Update $assignedFTE(FromWT)$, $assignedFTE(ToWT)$, $aveCap(FromWT)$, $aveCap(ToWT)$

computeObjectiveFunctionValue():

$value = weightFTE * scoreFTE + weightSkills * scoreSkills$

$$scoreFTE = \sum_{j=1}^{numOfWorkTypes} (targetFTE(j) - assignedFTE(j))^2$$

$$scoreSkills = \sum_{j=1}^{numOfWorkTypes} (aveCap(j) - bestCap(j))^2$$

allowableMove(*i*, *FromWT*, *ToWT*, *deltaOcc*)

If the following constraints remain satisfied after moving *deltaOcc* of occupancy from work type *FromWT* to work type *ToWT*, then return *True*; else return *False*.

- (c1) If *usePrimaryRes* = *True* then agent *i* must be assigned primary responsibility for one work type.
- (c2) *MinNumWTPerAgent* and *MaxNumWTPerAgent* constraints are satisfied.
- (c3) $X(i, j) > 0$, only if $ACap(i, j) \geq 0$.
- (c4) *numOfAssignedWTs(i)* does not decrease

(Note: this constraint is enforced after we have learned from simulation results that the more sharing of agents, the better the performance in terms of service levels and ASA)

Section 5: Handling input changes at run time

1. For all agents: when input parameters for an agent has changed, change this agent's occupancies accordingly:
 - 1.1. When target total occupancy changes.
 - 1.1.1. If increased, add the increased portion to some work type (heuristic: the work type with highest predicted workload where this agent has occupancy.)
 - 1.1.2. If decreased, we go through the list of work types this agent has non-zero occupancy, decrease occupancy amount as much as possible but still keep it non-zero.
 - 1.2. When user specified primary responsibility work type changes: readjust this agent's occupancy for the old and new primary responsibility work type.
 - 1.3. When this agent's skill levels change:
 - 1.3.1. Recalculate this agent's capabilities. Do nothing if there are no changes in the capabilities.
 - 1.3.2. If the capabilities changed: for each work type j , if this agent had non-zero occupancy for this work type, but is now incapable of handling work type j , move all occupancy from j to another work type. (Heuristic: the work type with highest predicted workload where this agent has capability.)
 - 1.4. Changes in allowed work types. Do step 1.3.2 when this agent has non-zero occupancy for a work type that is no longer an allowed work type.
2. For all work types: when work type parameter change,
 - 1.1. If workload or staffing priorities change, recompute *targetFTE* for all work types
 - 1.2. If minimal skill requirements change for some work types, recompute agent capabilities for these work types. For a work type where an agent had non-zero occupancy but is now not capable of handling, move this agent's occupancy from this work type to another one.
3. Call **generateMatrix**: at any step in the computation, if the *score* in the resulting matrix is close enough to the previous score, stop and return the matrix.

Section 6: (Near) Future work

- Advise: when the *assignedFTE* for each work type is far below *targetFTE*, it is most likely because there are not enough agents with the correct skills. Inform supervisors of that.

Automatic Generation of Agent Responsibility Matrix (A brief description)

The agent responsibility matrix specifies for each agent, the percentage of time the agent spends on each call type. This percentage number for agent i and call type j is called *occupancy*. The sum of an agent's occupancies for all call types is the *total occupancy* of the agent.

The input to the matrix generation algorithm includes are:

- Agent skills: the knowledge level of an agent in a given area
ex: Bill is skilled at different levels in Voice, Email, Fax, H/W & S/W

Agent Name	Voice	Email	Fax	Hardware	Software
Bill S 1111	9	4	4	0	2

- Agent total occupancy: for an agent, the % of available time of a workday that is his actual work time (50%, 85%, ...)
- Worktype skills: the knowledge level each worktype requires
ex: worktype CustomService/Call/S/W requires skills in voice, and software

Worktype Name	Skills Required				
	Voice	Email	Fax	Hardware	Software
CustomService, Call, S/W		5			6
CustomService, Email, H/W			5		6
Order, H/W Fax				5	6

- Workload for each work type.

An example of responsibility matrix generated automatically is as follows:

Agent	Total Occ	Call, S/W	Email, H/W	Order, H/W, Fax
Bill S	90%	90%		
Patrick U	80%		40%	40%
Randy C	80%		50%	30%
Susan G	85%	10%	40%	35%

Algorithm:

The objective of generating responsibility matrix is to distribute agents to work on different work types so that each work type has appropriate number of assigned agents according to its workload. Traditional approach uses Erlang computation to determine

staffing requirements; however, Erlang formula does not work well in skill-based routing with complicated agents sharing. The following algorithm is used to determine staffing requirements, instead of traditional Erlang computation. Our algorithm is as follows (this is a brief description, a great amount of detail is omitted here):

1. Initialize occupancies: for each agent, randomly assign occupancies for work types this agent has sufficient skills for, and in this process, ensure that the occupancies for each agent add up to his/her total occupancy.
2. Assign occupancies by *iterative repair*:
For each agent, randomly move this agent's occupancy from one work type to another. If this move results in "better" staffing according to the workloads of all work types, then we update the existing matrix according to this random move; otherwise, we keep the matrix as it is, and repeat the process.